Assimilation of multiple datasets results in large differences in regional to global-scale NEE and GPP budgets simulated by a terrestrial biosphere model

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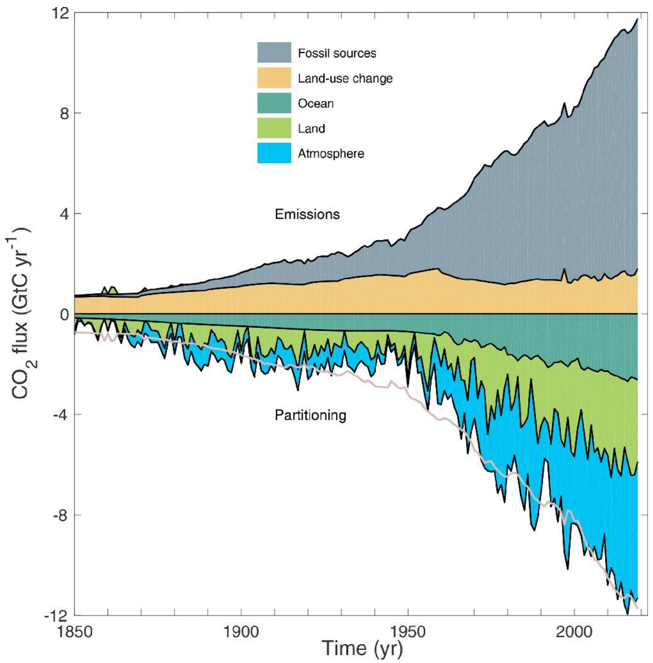
Terrestrial vegetation: the most uncertain component of the Global Carbon Cycle

Quantifying and reducing uncertainty in global C budget projections using Terrestrial Biosphere Models

The Global Carbon Budget



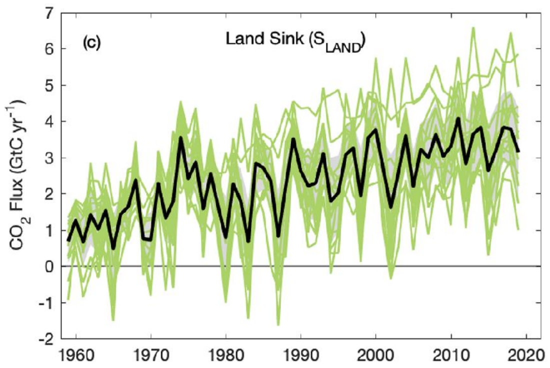
@Friendlingstein et al. (2020)

3.4 ± 0.9 $GtC.yr^{-1}$
over 2010-2020

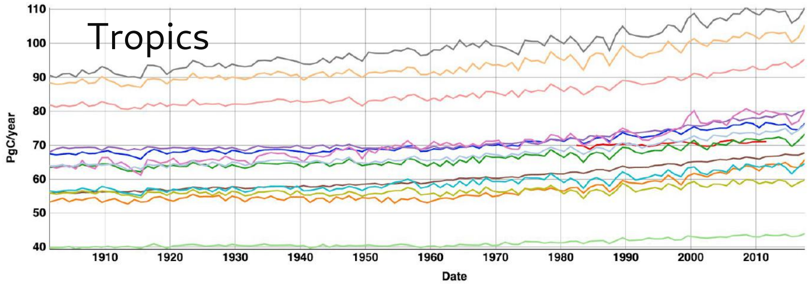
NEE = GPP-TER

Simulations by Terrestrial Biosphere Models

land C sink - NEE



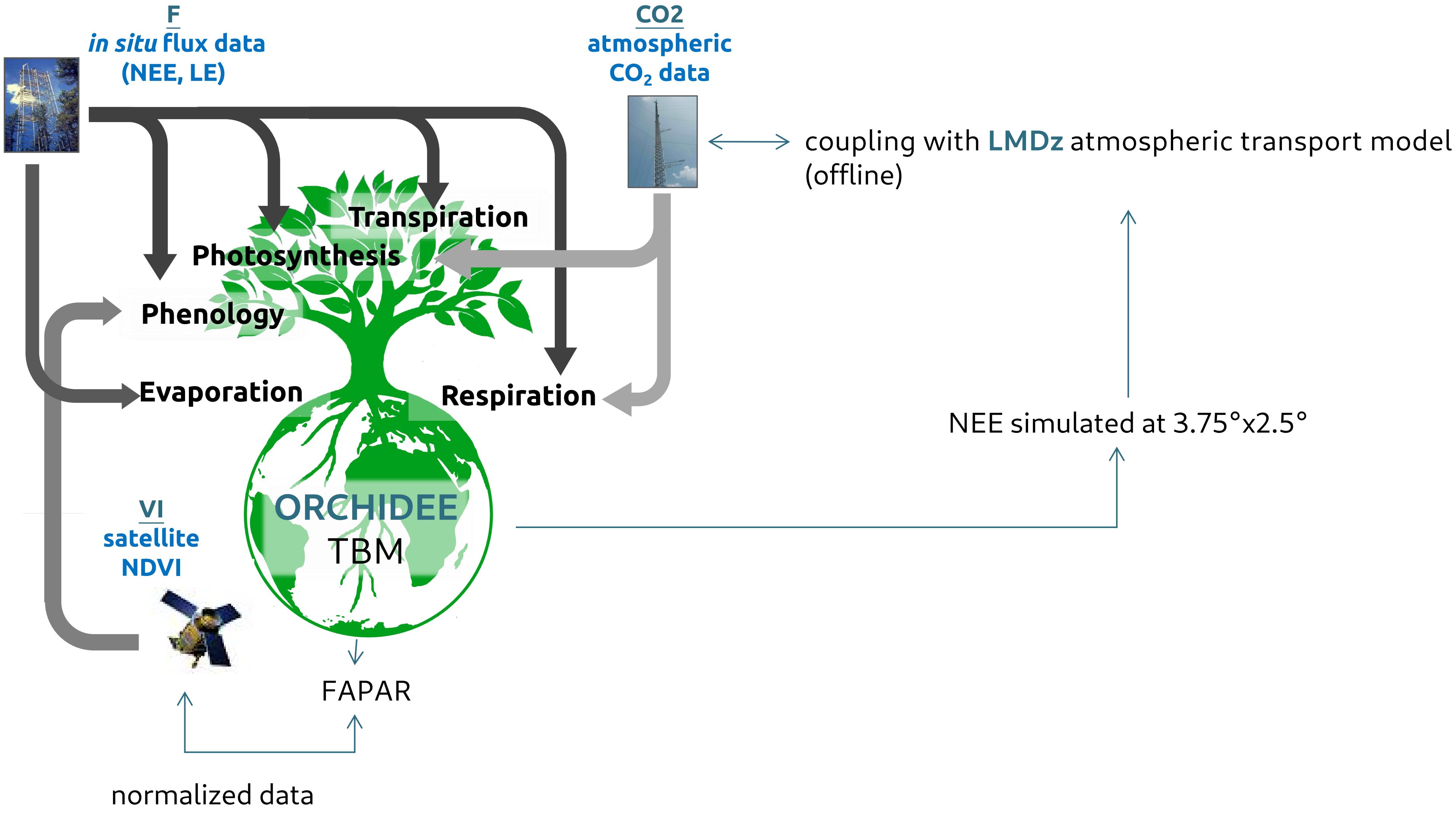
Gross C flux (GPP)



results from TRENDY V9

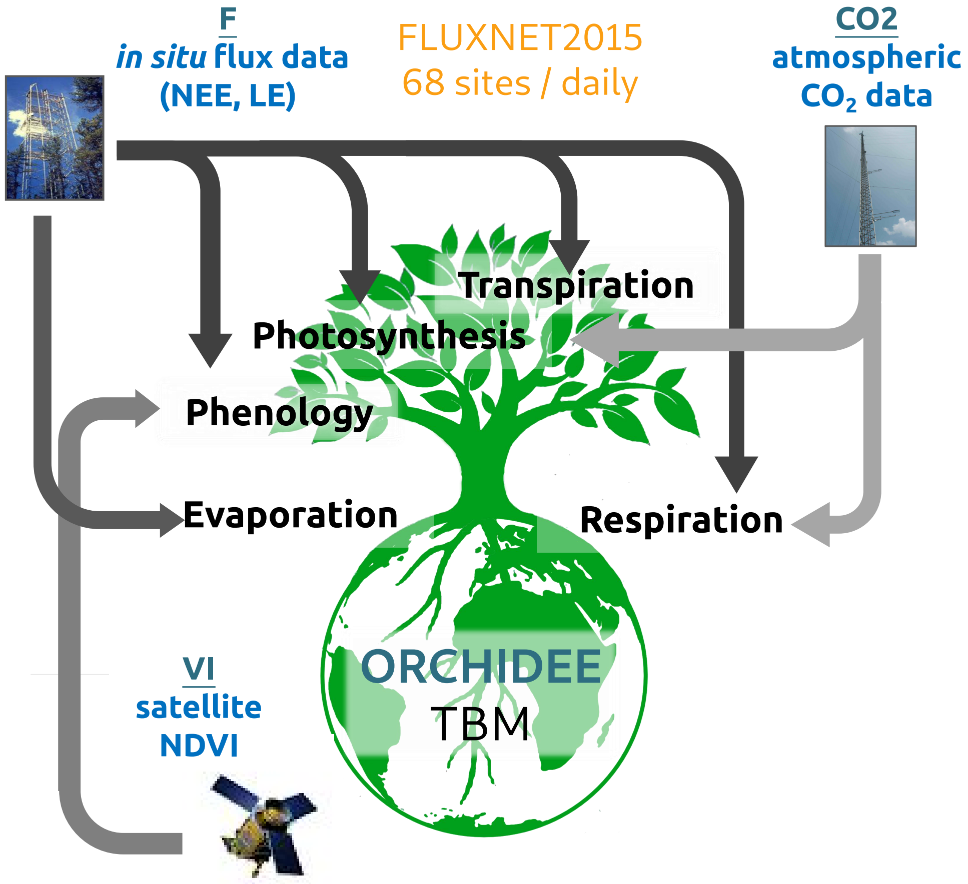
Model - data fusion to optimize ORCHIDEE parameters

Datasets



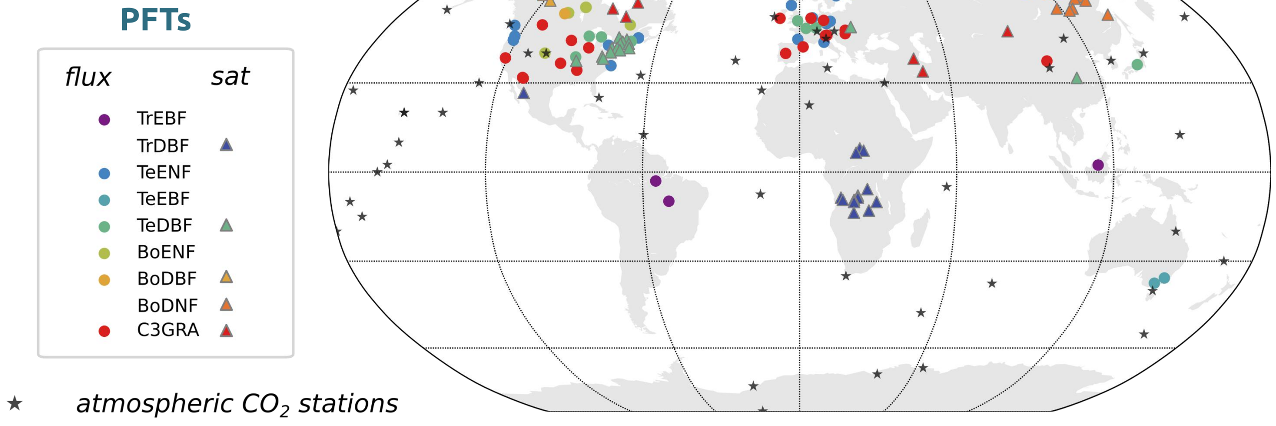
Model - data fusion to optimize ORCHIDEE parameters

Datasets



MODIS coll. 5
15 pixels / PFT
daily / 0.72°
2000-2010

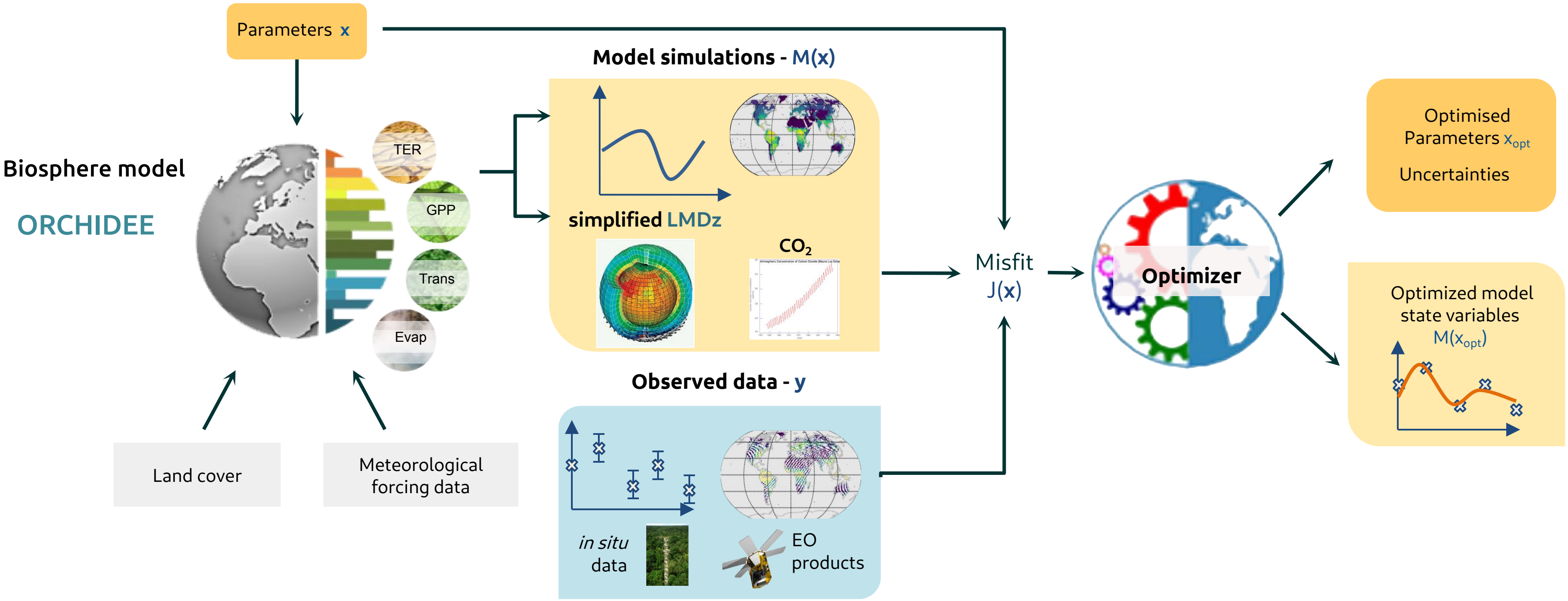
53 surface stations
monthly
2000-2009



- Not an up-to-date reanalysis of the C cycle!
- Assessment of the useful informational content provided by different data-streams on global C fluxes wrt the set-up and the model structure

ORCHIDAS assimilation framework

https://orchidas.lsce.ipsl.fr



focus on NEE & GPP

Misfit function

$$
\begin{aligned}
J(\mathbf{x}) \;=\; & \frac{1}{2}\Big[\left(H_{LMDz}{\circ}H_{ORCH}(\mathbf{x})-\mathbf{y}^{CO2}\right)^{t}.\mathbf{R}^{-1}_{\mathbf{CO2}}.\left(H_{LMDz}{\circ}H_{ORCH}(\mathbf{x})-\mathbf{y}^{CO2}\right)+ \\
& \left(H_{ORCH}(\mathbf{x})-\mathbf{y}^{F}\right)^{t}.\mathbf{R}^{-1}_{\mathbf{F}}.\left(H_{ORCH}(\mathbf{x})-\mathbf{y}^{F}\right)+ \\
& \left(H_{ORCH}(\mathbf{x})-\mathbf{y}^{VI}\right)^{t}.\mathbf{R}^{-1}_{\mathbf{VI}}.\left(H_{ORCH}(\mathbf{x})-\mathbf{y}^{VI}\right)+ \\
& \left(\mathbf{x}-\mathbf{x}^{b}\right)^{t}.\mathbf{B}^{-1}.\left(\mathbf{x}-\mathbf{x}^{b}\right)\Big]
\end{aligned}
$$

Data Assimilation Experiments

Experiment name	Flux data	NDVI data	Atmospheric CO_2 concentrations	Number of optimized parameters	Number of observations
F	x			133	150 792
VI		x		19	149 916
CO2			x	114	6 360
F+VI	x	x		152	300 708
F+CO2	x		x	182	157 152
VI+CO2		x	x	114	156 276
F+VI+CO2 **F+VI+CO2-2steps**	x	x	x	182	307 068

Optimized parameters

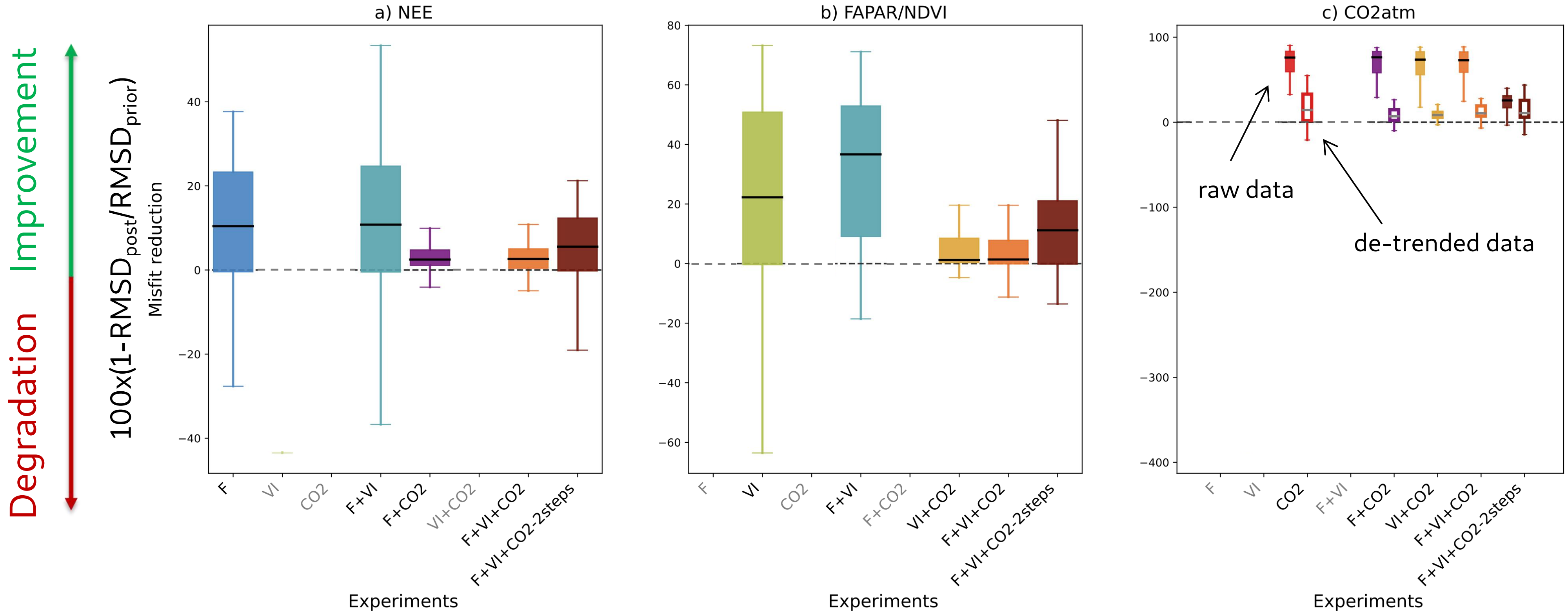
Processes	Parameters	Obs. constraint
Photosynthesis	5 parameters / PFT	F,CO2
Soil Water Availability	1 parameter / PFT	F,CO2
Phenology	5 parameters / PFT	F,VI,CO2
Respiration	3 parameters + $KsoilC_{site}$ + $KsoilC_{reg}$ (30 regions)	F,CO2 F CO2

Scientific Questions

- Analyze the compatibility, complementarity, and usefulness, of the different data streams in the frame of a global-scale C data assimilation system
- Assess their potentials to improve the realism of the space-time distribution of **NEE** and **GPP**

Overall fit to the observations

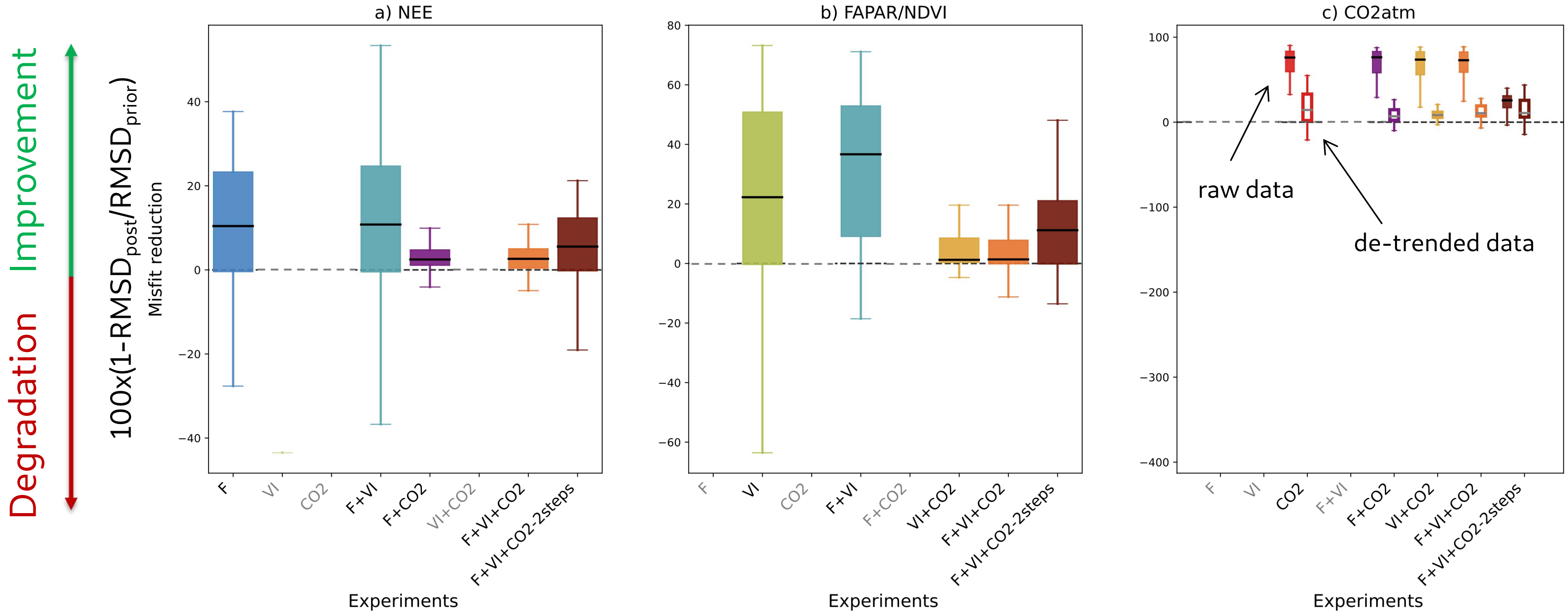
Reduction of the model-data mismatch wrt the variables assimilated



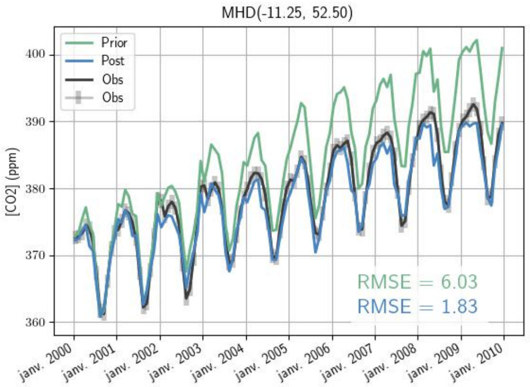
- Model improvement usually better for the experiments where a data stream is assimilated alone
- For the multiple DA with CO2, the 2-step approach lead to the highest improvement wrt F and VI
- For CO2: slight differences wrt raw data, higher variability between experiments wrt de-detrended data

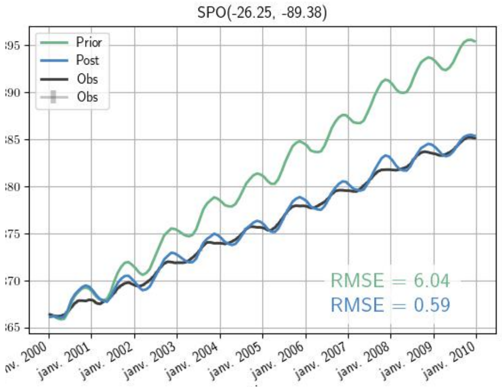
Overall fit to the observations

Reduction of the model-data mismatch wrt the variables assimilated



atmospheric CO_2 time series

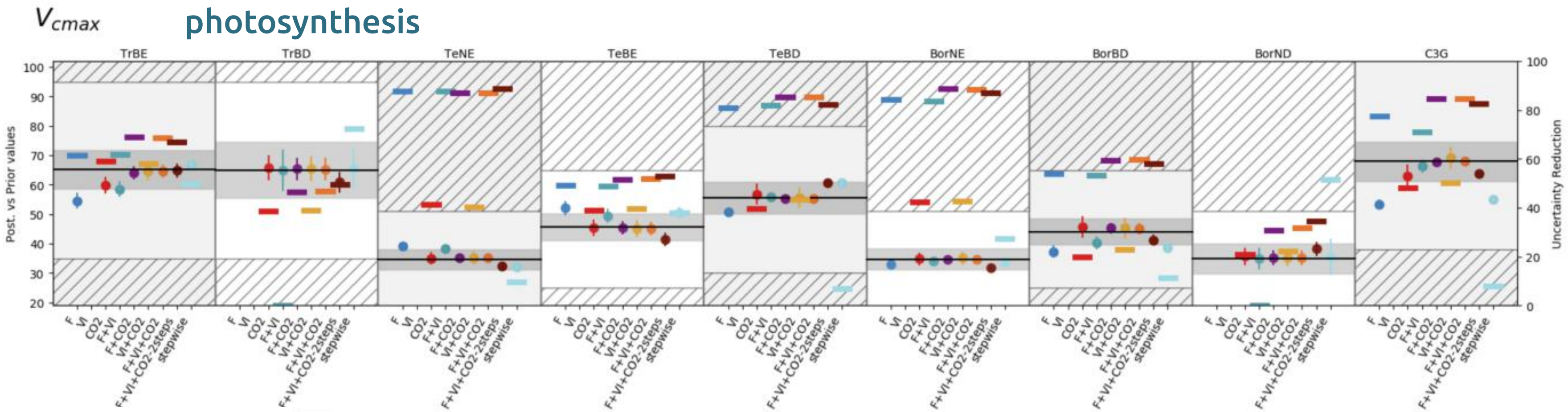




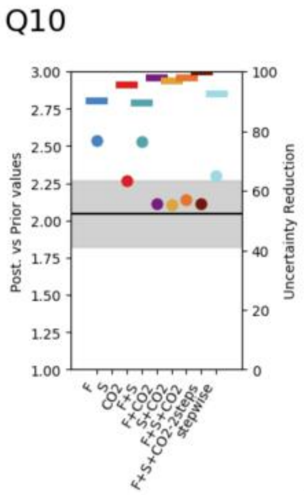
trend correction mostly achieved by the correction of the soil C disequilibrium (multiplicative $KsoilC_{reg}$ parameter)

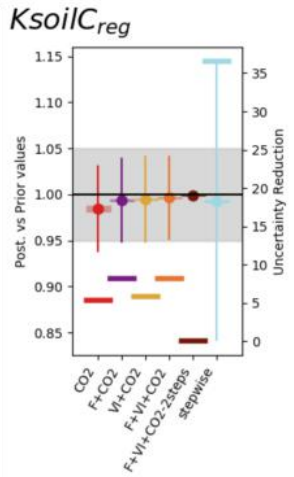
Parameter estimates and uncertainties

photosynthesis



respiration





- Highest departures from the prior values obtained for single-data stream assimilations
- Correcting the bias in atm. CO_2 trend prevails over the improvement of photosynthesis and phenology related parameters
  - higher changes obtained for F and VI, compared to CO_2
  - little variability among the 3 data-streams DA experiments (**but the 2steps one**)

Relative constraints brought by the different datasets

Influence matrix

$$\mathbf{S} = \mathbf{R}^{-1}\mathbf{H}^{\infty}\mathbf{A}\mathbf{H}^{\infty\mathbf{t}} \qquad \text{with} \qquad \mathbf{A} = [\mathbf{H}^{\infty\mathbf{t}}\mathbf{R}^{-1}\mathbf{H}^{\infty} + \mathbf{B}^{-1}]^{-\mathbf{1}}$$

(@ *Cardinali et al., 2004*)

Global Observation Influence (OI)

> gauges the average influence that each single observation has on the analysis

$$OI = \frac{tr(\mathbf{S})}{m}$$

Relative Degrees of Freedom for Signal (DFS)

> measures the relative contribution of the data stream *o* to the fit

$$DFS = 100 \times \frac{tr(\mathbf{S})}{tr(\mathbf{S_o})}$$

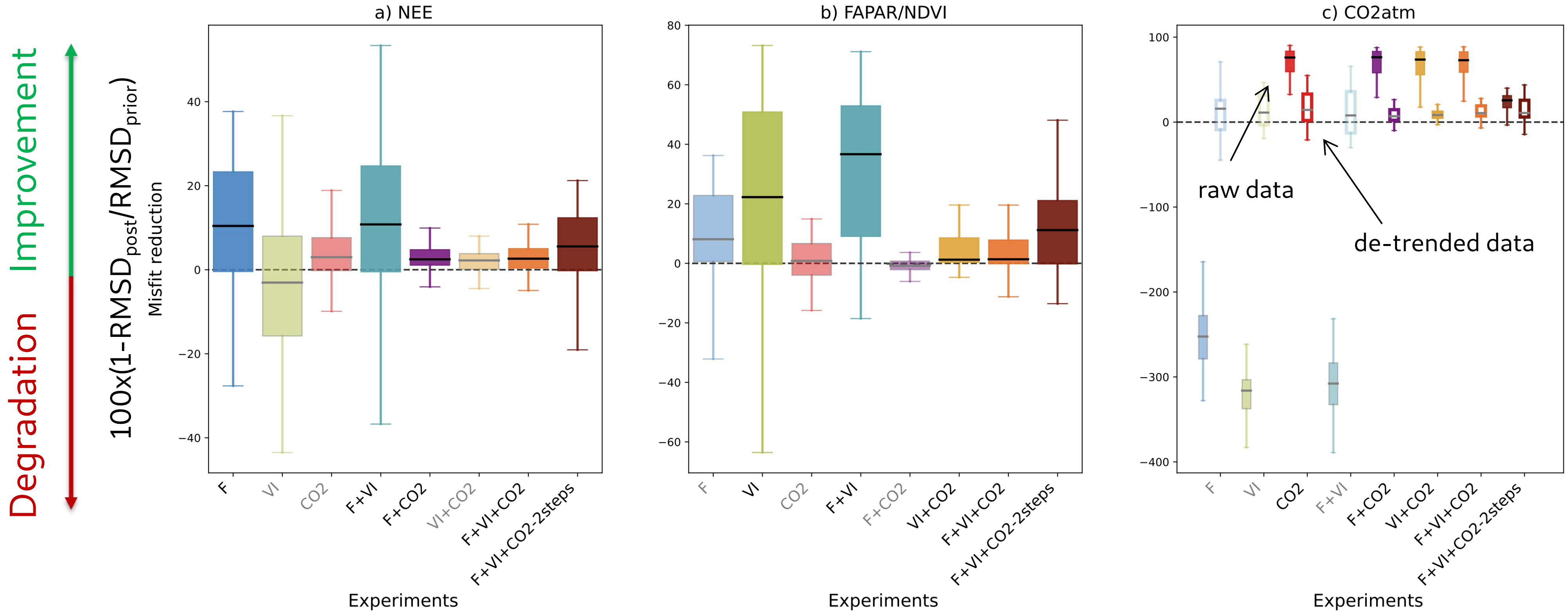
	OI		DFS	
	1-step	2-step	1-step	2-step
F	0.000586	0.000577	74.65	76.9
VI	0.000048	0.000048	11.12	11.68
CO2	0.002654	0.002035	14.23	11.42

~ x 5

- OI for CO_2 is about 5 times higher than that for F with about the same number of optimized parameters BUT about 25 times less observations > impact of the trend correction

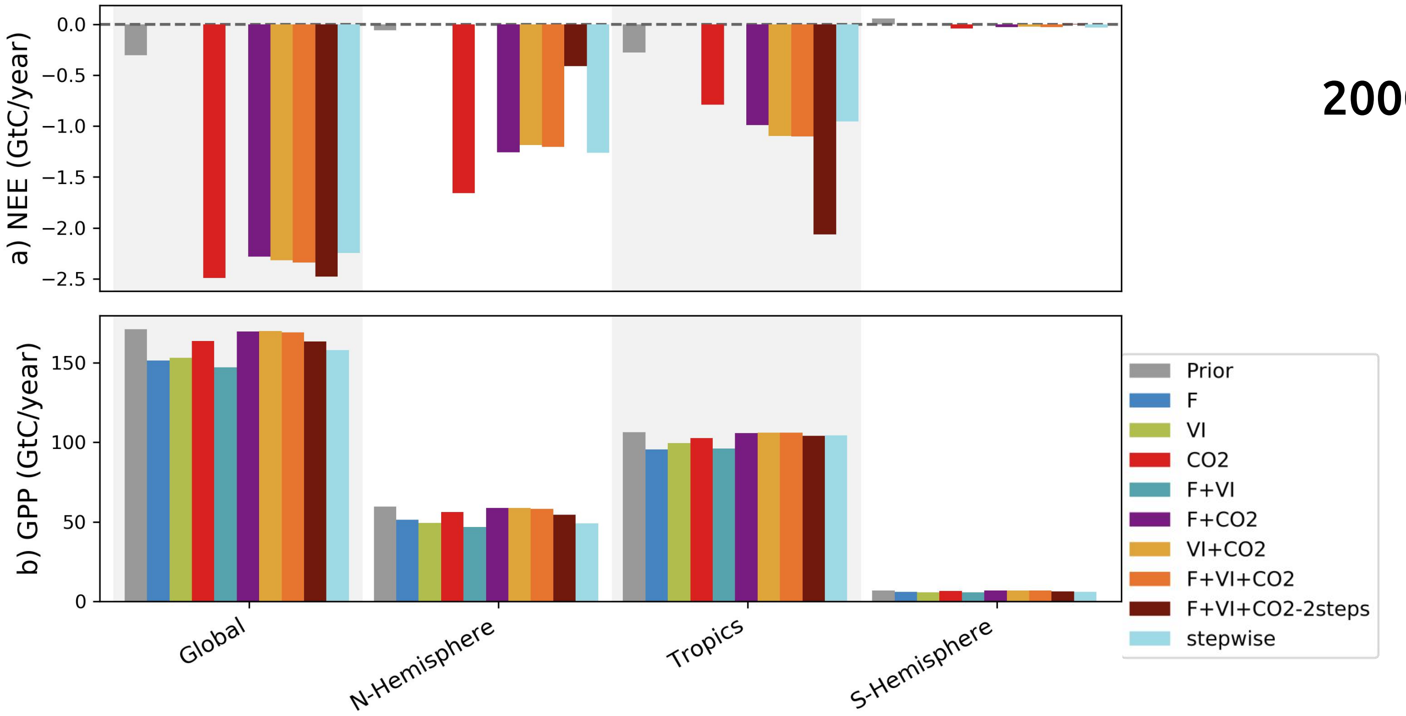
Overall fit to the observations

Reduction of the model-data mismatch for all variables



- Simulations using optimized parameters constrained by other data-streams > model degradation can be observed
- The joint assimilation experiments lead to improved model-data agreement and reduce the risk of model degradation (model overfitting wrt a given data-stream)

Impact of the assimilations on regional to global land C fluxes



2000-2009

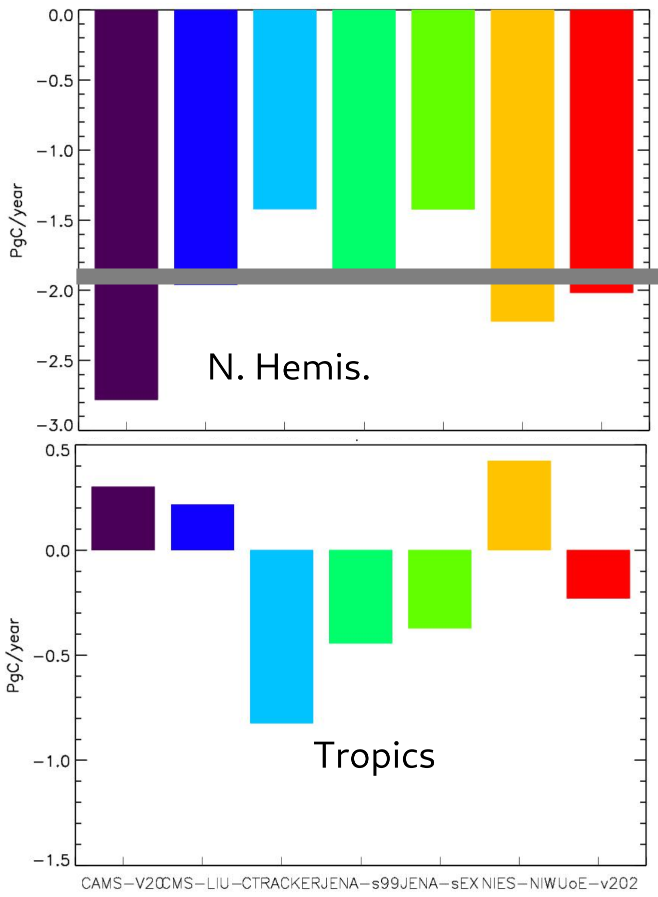
GCP: NEE = -2.9 GtC.yr^{-1} ± 0.8

- **F+CO2**, **VI+CO2**, and **F+VI+CO2** : similar NEE and GPP budgets across regions
- **CO2** and **F+VI+CO2-2step** experiments result in distinctly different estimates between N. Hemisphere and Tropics

Different NH - Tropics partitioning estimated by atmospheric inversions vs TBMs

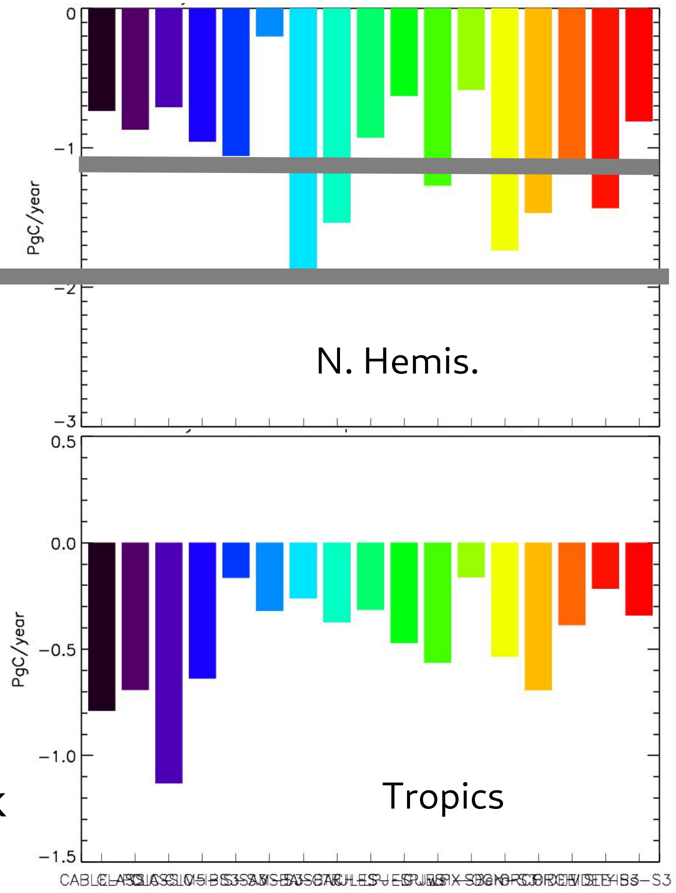
net C fluxes:
Mean over
2010-2020

Atm. inversions (GCP-2021)



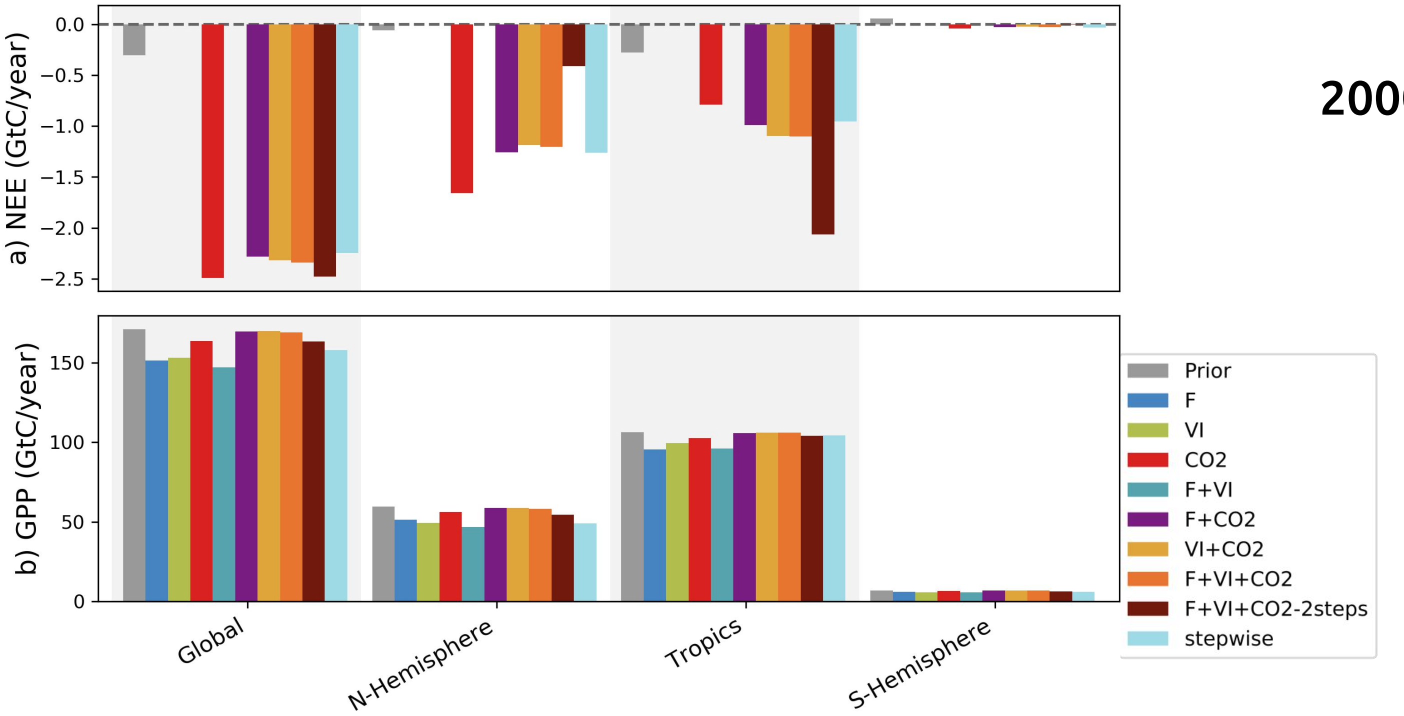
larger sink

TBMs (TRENDY - V10)



larger sink

Impact of the assimilations on regional to global land C fluxes



2000-2009

GCP: NEE = -2.9 $GtC.yr^{-1}$ ± 0.8

C budget partitioning between N. Hemisphere and Tropics

- **CO2** > similar regional partitioning as the atmospheric inversions
- **F+VI+CO2-2step** > typical partitioning pattern of TBMs' behavior
- **F+CO2**, **VI+CO2**, and **F+VI+CO2** > approximately equal C sink in the NH and tropics (=> unlike the general pattern for TBMs)

Take home messages

- Configuration matters

- Atmospheric CO_2 data are crucial for an accurate prediction of the distribution of the terrestrial land sink
  - challenges in handling model-data bias in Bayesian optimisation frameworks
  - sub-optimal optimization of the soil C disequilibrium with our approach based on a model spin-up without a long transient run (not TRENDY like)
  - 2step approach: illustrate how the informational content of the data-streams relative to C fluxes is enhanced once soil C disequilibrium is modeled in a more "realistic" way

- Diagnostics for system evaluation
  - relative informational content brought by each data stream
  - consistency of the error statistics on parameters and observations (Desrozier et al. (2005))
  - optimisation efficiency

- Assimilating simultaneously multiple datasets is preferable to optimize the values of the model parameters and avoid model overfitting